On behalf of the
NPLQCD collaboration

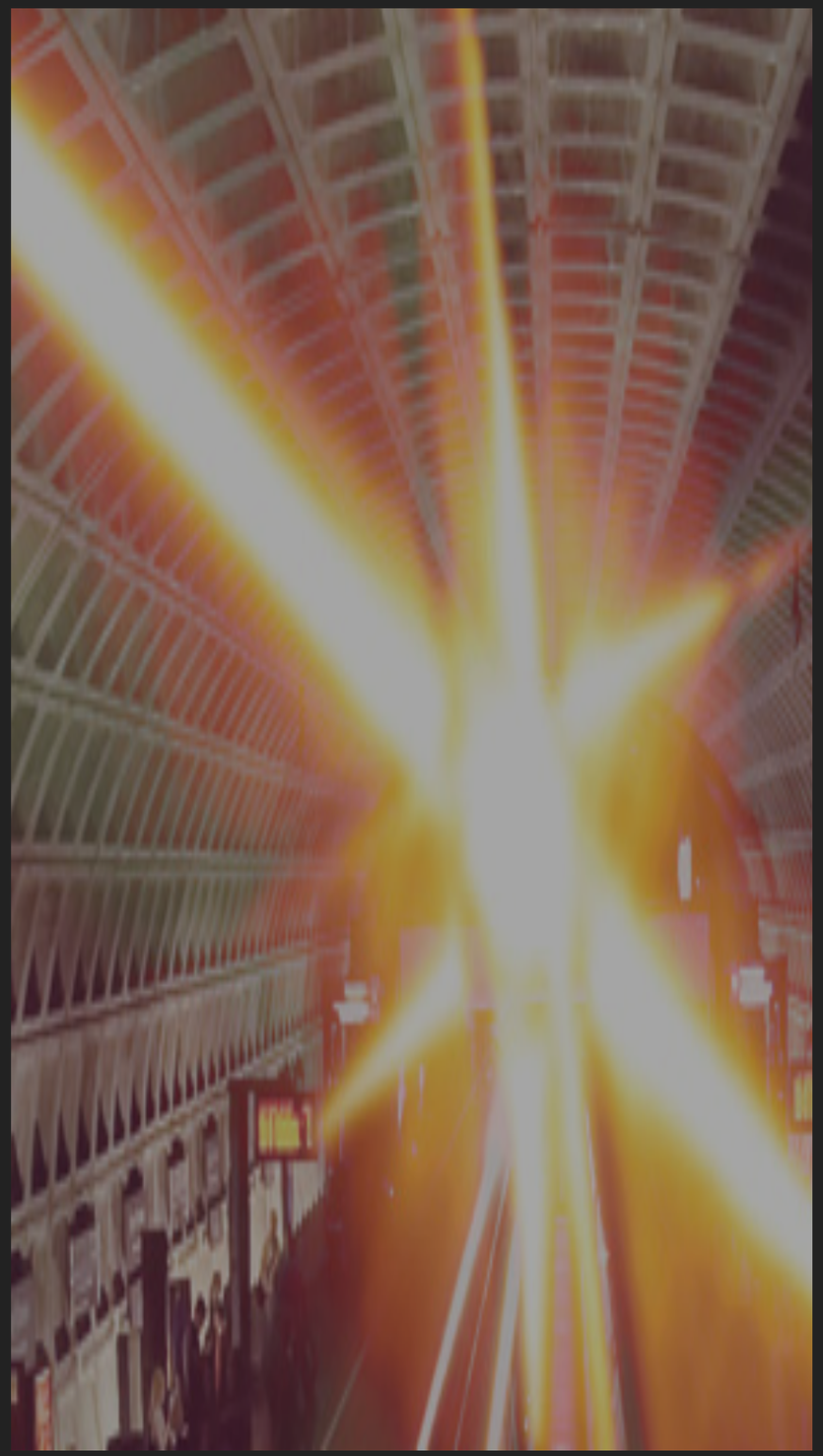
WILL DETMOLD MIT

NUCLEAR MATRIX ELEMENTS FOR BSM SEARCHES FROM LATTICE QCD

Snowmass Rare Processes and Precision Frontier Town Hall Meeting, Oct 2 2020

NUCLEI AT THE INTENSITY FRONTIER

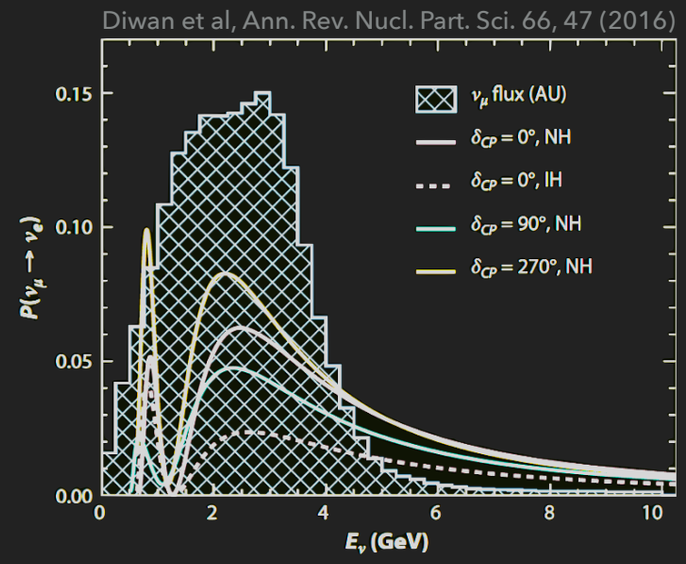
- Seek new physics through quantum effects
- Precise experiments
  - Sensitivity to probe the rarest interactions of the SM
  - Look for effects where there is no SM contribution
- Major component is nuclear targets
- Important focus of HEP/NP experimental program
  - Neutrino physics
  - Dark matter direct detection
  - Charged lepton flavour violation, EDMs, ββ-decay,

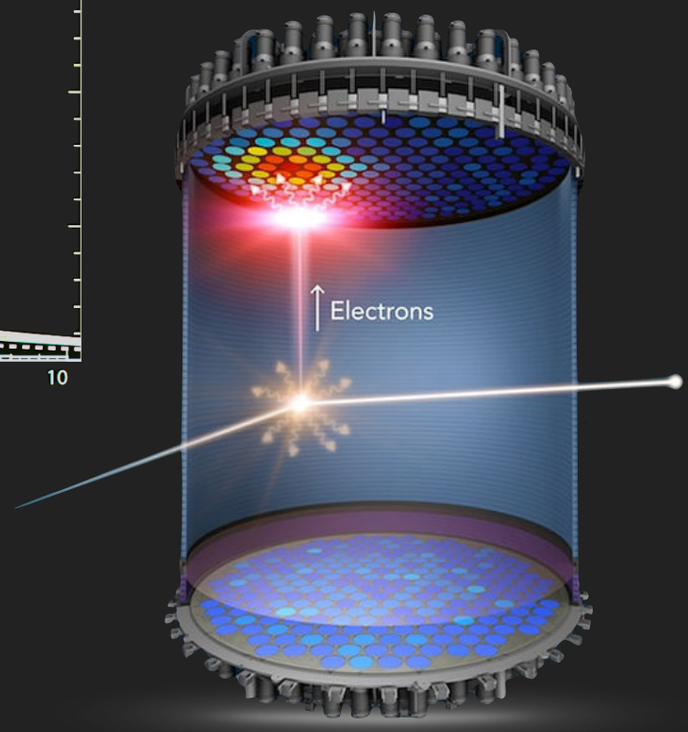


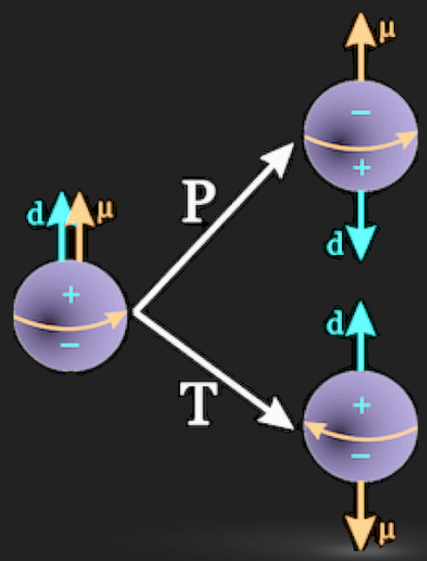
NUCLEI IN NEW PHYSICS

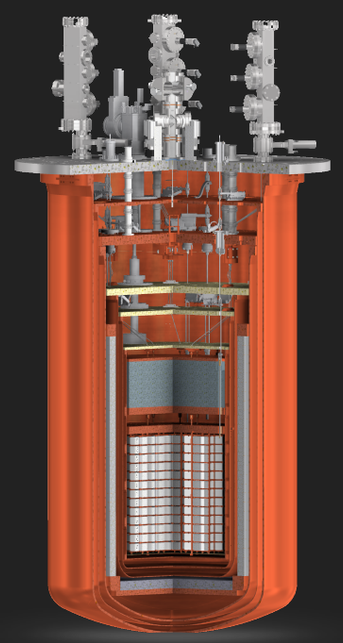
- Deep Underground Neutrino Experiment
  - Need to know interactions with argon over a wide range of energies
- Scalar currents
  - Dark matter direct detection
  - Lepton flavour violation: μ2e
  - Precision isotope spectroscopy
- Tensor currents
  - Electric dipole moments of neutrons and nuclei
  - Velocity dependent dark matter interactions
- Neutrinoless double beta decay

Diwan et al, Ann. Rev. Nucl. Part. Sci. 66, 47 (2016)





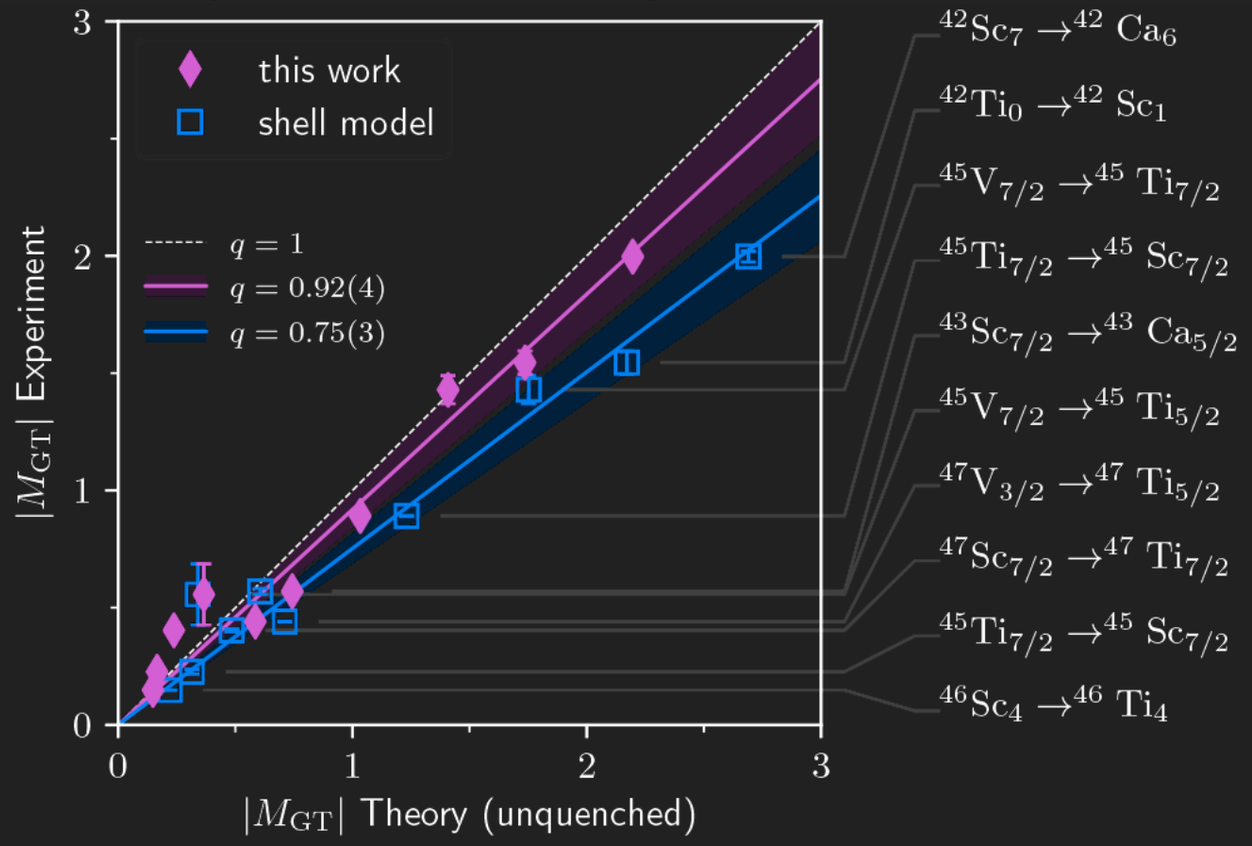




NUCLEAR UNCERTAINTIES

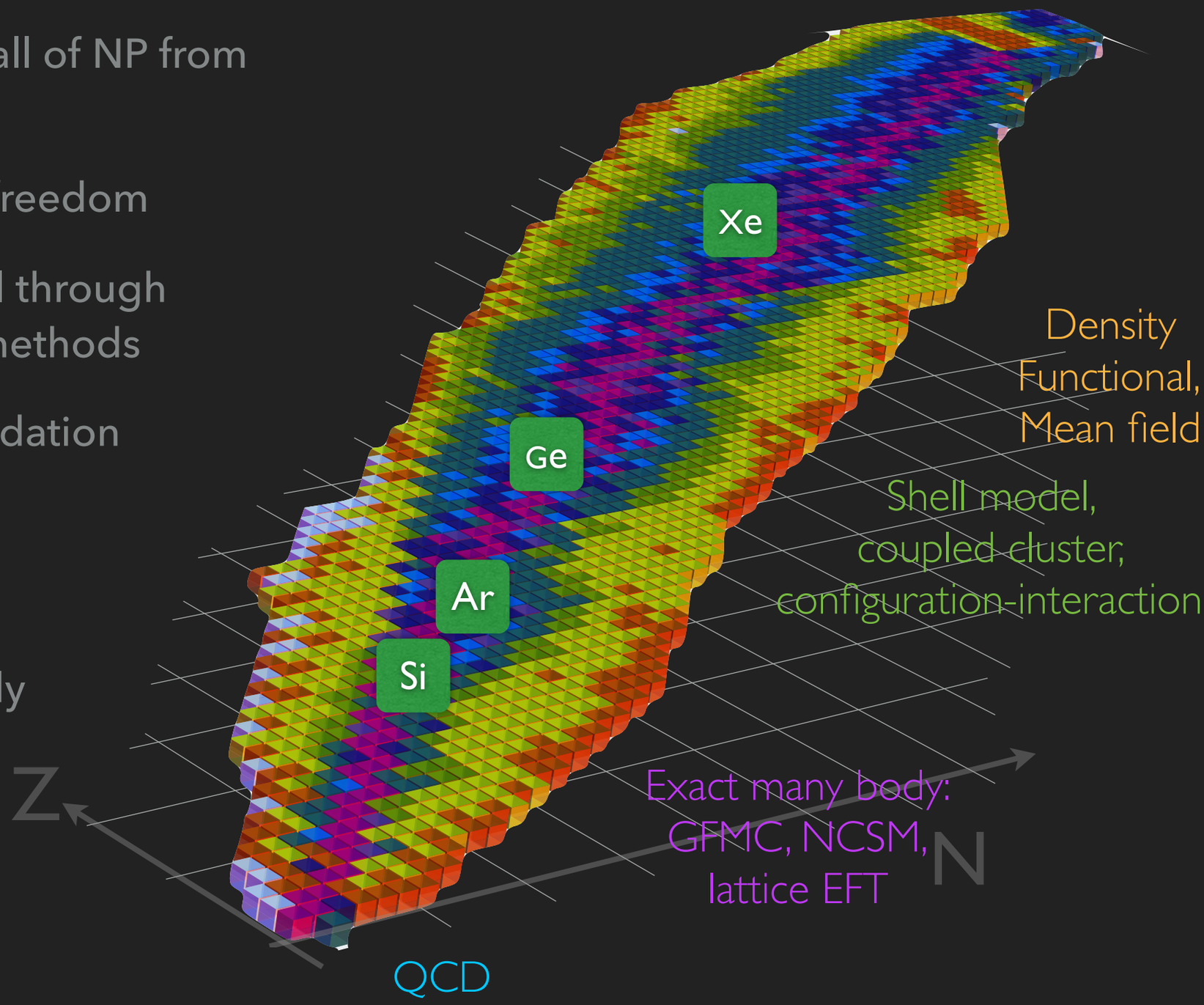
- How well do we know nuclear matrix elements?
- Gamow-Teller transitions in nuclei
  - Well measured for large range of nuclei (30<A<60)
  - Matrix elements systematically off by 20–30%
  - Correct using 2 body currents where they are known
- Goal: Fundamental understanding and constraint from the Standard Model

P Gysbers et al, Nature Phys. 15 (2019) no.5, 428-431



PRECISION NUCLEAR PHYSICS

- Very challenging to explore all of NP from the SM (QCD)
- Exploit effective degrees of freedom
- Establish quantitative control through linkages between different methods
  - Lattice QCD forms a foundation determines few body interactions & matrix elements
  - Match EFT and many body techniques onto LQCD



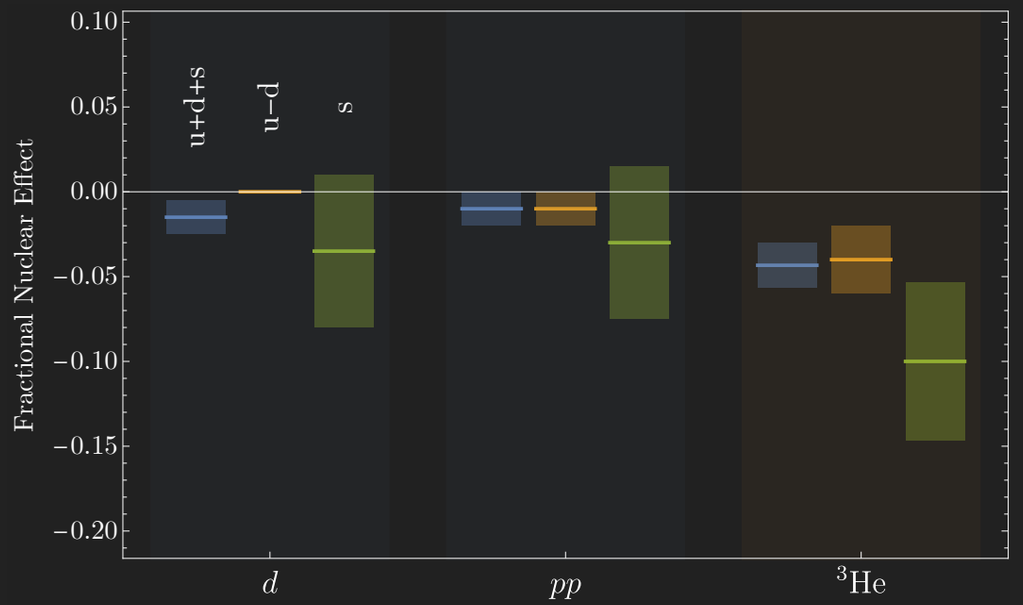
DEVELOPING THE TOOLS FOR LQCD NUCLEI

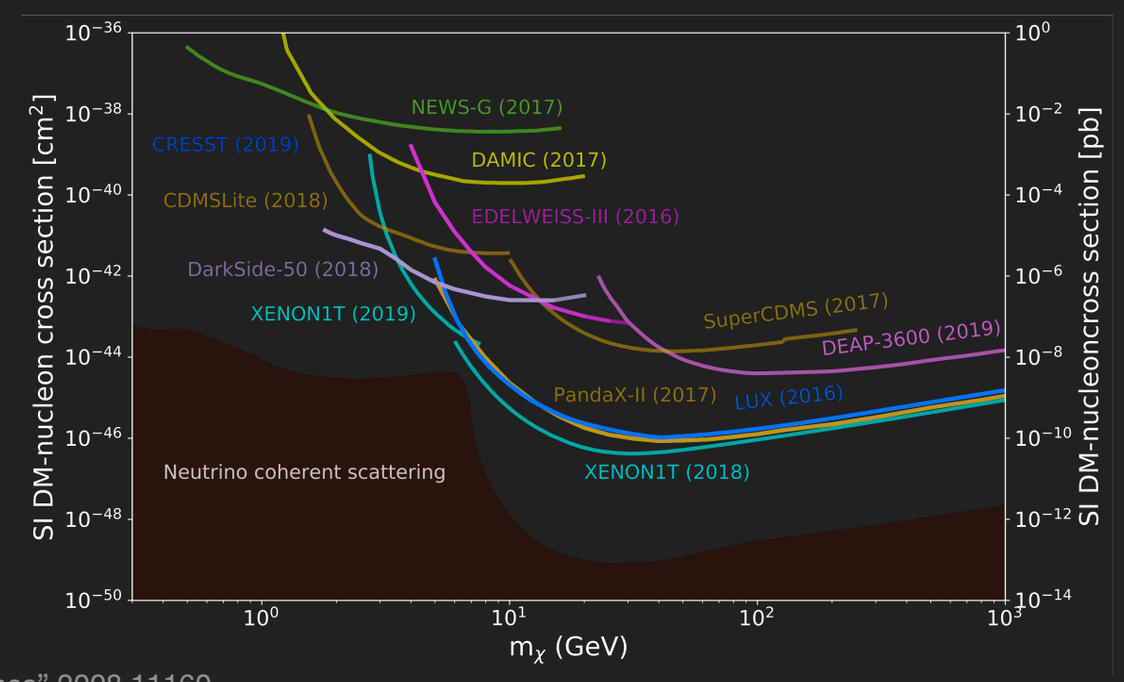
Present

- Case study QCD with unphysical quark masses (m_π~800 MeV, 450 MeV)

1. Spectrum and scattering of light nuclei (A<5) [PRD 87 (2013), 034506]
2. Nuclear structure: magnetic moments, polarisabilities, parton structure (A<5) [PRL **113**, 252001 (2014), PRL **116**, 112301 (2016), PRD **96** 094512 (2017), 2009.05522]
3. Nuclear reactions: np→dγ [PRL **115**, 132001 (2015)]
4. Gamow-Teller transitions: pp→dev, $g_A(^3H)$ [PRL **119** 062002 (2017)]
5. Double β decay: nn→ppee, $\pi^-\to\pi^+ee$ [PRL **119**, 062003 (2017),2004.07404]
6. Scalar/tensor currents (A<4) [PRL 2018]

Scalar matrix elements





Review: ”Nuclear matrix elements from lattice QCD for electroweak and beyond-Standard-Model processes” 2008.11160

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Future

- Refine LQCD calculations with physical quark masses and better control LQCD systematics
- Matching to nuclear EFTs and constraints on models
- Connection to experiment

Goal of whitepaper: overview progress and expectations

Needs: continued investment in exascale+ computing and software

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